

A

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE



Applicant : George H. Beall and David L. Weidman
Serial No. : Not Yet Assigned
Filed : Simultaneously Herewith
For : ATHERMAL OPTICAL DEVICE



Prior Application:

U.S. Serial No. : 09/101,630
Filed : July 14, 1998
For : ATHERMAL OPTICAL DEVICE
Applicant (U.S.) : George H. Beall and David L. Weidman
Int. Appl. No. : PCT/US96/13062
Int. Filing Date : 7 August 1996 (07.08.96)
Priority Date : 16 January 1996 (16.01.96)

Box Patent Application
Commissioner of Patents and Trademarks
Washington, D.C. 20231

FILING UNDER 37 CFR 1.53(b)

Express Mail Information

Date of Deposit: December 1, 1998

Express Mail mailing label number: EJ266200952

09203166 120198

FILING UNDER 37 CFR §1.53(b)

Transmitted herewith for filing is the patent application of:

Inventor : George H. Beall and David L. Weidman
For : ATHERMAL OPTICAL DEVICE

Enclosed are:

1. Disclosure (12 pages)
2. Claims (6 pages)
3. Abstract (1 page)
4. Drawings (10 figures, 5 sheets, informal)
5. Declaration and Power of Attorney (3 pages)
6. Preliminary Amendment (6 pages)
7. Check for \$976.00
8. Express Mail Information (1 page)
9. Return Receipt Postcard (1 card)

This is a X continuation
— divisional

application under 35 USC §120 of pending prior application No. 09/101,630 filed on July 14, 1998, which is the U.S. national phase filing of PCT/US96/13062 filed on August 7, 1996, which claims the benefit under 35 USC §119(e) of U.S. Provisional Application No. 60/010,058, filed on January 16, 1996.

Oath or Declaration

— Newly executed (original or copy)
X Copy from prior application No. 09/101,630 (37 CFR 1.63(d))

X Incorporation By Reference

The entire disclosure of the prior application, from which a copy of the oath or declaration is supplied, is considered as being part of the disclosure of the accompanying application and is hereby incorporated by reference therein.

- X With respect to the prior copending U.S. application from which this application claims benefit under 35 USC § 120, the inventors of the claims of this application are the same as the inventors of the claims of the prior application.
- X Applicant hereby claims the benefit under 37 USC § 363 and 35 USC § 120 of the August 7, 1996 filing date of PCT/US96/13062.
- X Applicant hereby claims the benefit under Title 35, United States Code § 119(e) of United States Provisional Patent Application No. 60/010,058 filed January 16, 1996.
- X A preliminary amendment canceling Claims 1-40 and replacing them with Claims 41-61 is enclosed. The following filing fee calculation is based on the claims remaining in this application after the entry of this preliminary amendment.

LARGE ENTITY

The filing fee has been calculated as shown below:

Basic Fee:		\$ 790.00
Total Claims:	21 - 20 = 1 x 22	22.00
Indep. Claims:	5 - 3 = 2 x 82	164.00
Multiple dep. claim(s), if any:	+ 270	<u>0.00</u>
Total:		\$ 976.00

A check in the amount of \$976.00 is enclosed.

The Commissioner is hereby authorized to charge any additional fees which may be required by this paper, or credit any overpayment, to Deposit Account No. 11-1158.

- X The prior application is assigned of record to Corning Incorporated.
- X The power of attorney in the prior application is to Maurice M. Klee, Reg. No. 30,399; Alfred L. Michaelson, Reg. No. 24,511; and Edward F. Murphy, Reg. No. 38,251.
- X The power of attorney appears in the original papers in the prior application.

Address all future communications to:

Maurice M. Klee, Ph.D.
Attorney at Law
1951 Burr Street
Fairfield, CT 06430
(203) 255-1400

Respectfully submitted,

Date: 12/1/98

Maurice Klee

Maurice M. Klee, Ph.D.
Reg. No. 30,399
Attorney for Applicant
1951 Burr Street
Fairfield, CT 06430
(203) 255-1400

2025 RELEASE UNDER E.O. 14176

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Applicant : George H. Beall and David L. Weidman
Appl. No. : Not Yet Assigned
Filed : Simultaneously Herewith
For : ATHERMAL OPTICAL DEVICE

Commissioner of Patents and Trademarks
Washington, D.C. 20231

PRELIMINARY AMENDMENT

Prior to its initial examination, please amend the above-identified application as follows:

IN THE SPECIFICATION:

Please insert before the first line of the specification:

--CROSS REFERENCE TO RELATED APPLICATIONS

This is a continuation of U.S. Application No. 09/101,630 filed on July 14, 1998, which is the US national phase filing of PCT/US96/13062 filed on August 7, 1996, which claims the benefit under 35 USC §119(e) of U.S. Provisional Application No. 60/010,058, filed on January 16, 1996, the contents of each of which in their entireties are hereby incorporated by reference.--

IN THE CLAIMS:

Please amend the claims by canceling Claims 1-40, without prejudice, and replacing them with the following Claims 41-61:

--41. An article comprising an optical fiber with a refractive index grating having a length and a reflection wavelength λ at a given temperature within an operating temperature range; wherein the optical fiber is attached to a support member, said support member having a negative coefficient of thermal expansion selected such that λ is substantially temperature independent over said operating temperature range.--

--42. An article according to claim 41, wherein the support member has a negative coefficient of thermal expansion selected such that $|d\lambda/dT|$ is approximately 10% of $d\lambda/dT$ of an otherwise identical comparison grating that is not attached to a support member.--

--43. An article according to claim 41, wherein the operating temperature range includes 20°C.--

--44. An article according to claim 43, wherein the operating range includes at least a portion of the range -20° to 65°C.--

--45. An article according to claim 41, wherein the optical fiber is a silica-based optical fiber.--

--46. An article according to claim 41, wherein the optical fiber is attached to the support member at least over the length of the refractive index grating.--

--47. Article according to claim 41, wherein said optical fiber is attached to the support member at bonding platforms.--

--48. Article according to claim 47, wherein said bonding platforms are configured such that said refractive index grating is spaced from said support member.--

--49. Article according to claim 47, wherein said bonding platforms comprise a material selected to have a coefficient of thermal expansion that is substantially matched to the coefficient of thermal expansion of the optical fiber.--

--50. Article according to claim 41, wherein said support member comprises a first negative thermal expansion coefficient member bonded to a second positive thermal expansion coefficient member, said first and second members selected to provide a support member having a desired value of the negative thermal expansion coefficient.--

--51. An athermal optical device comprising:

a negative expansion substrate having an upper surface; and

20150702

a thermally sensitive, positive expansion optical component affixed to the substrate upper surface at at least two spaced apart locations.--

--52. The device according to claim 51, in which the optical component is an optical fiber grating.--

--53. The device according to claim 51, in which the optical component is a waveguide.--

--54. An athermal optical fiber grating device comprising;
a negative expansion substrate having an upper surface and first and second ends;
an optical fiber affixed to the substrate upper surface at at least two spaced apart locations; and
a grating defined in the optical fiber between and at a distance from each substrate end.--

--55. The device according to claim 54, in which the optical fiber is affixed to the substrate upper surface at first and second spaced apart locations, the first location is between the grating and the first substrate end and the second location is between the grating and the second substrate end.--

--56. The device according to claim 54, wherein the fiber is affixed by a layer of attachment material.--

--57. The device according to claim 56, in which the attachment material is one of a polymer, a frit and a metal.--

--58. The device according to claim 57, in which the polymer is an epoxy adhesive.--

--59. The device according to claim 55, further comprising a bonding pad having a coefficient of expansion intermediate between that of the fiber and the substrate mounted between the optical fiber and the substrate at each of the first and second locations, the optical fiber being bonded to each bonding pad and each bonding pad being affixed to the substrate.--

--60. Apparatus comprising:

- (a) a substrate having a negative coefficient of thermal expansion;
and
- (b) a fiber grating affixed to the substrate.--

--61. In an apparatus having a fiber grating affixed to a device where the device provides thermal compensation to the fiber grating, the improvement wherein the device comprises a material having a negative coefficient of thermal expansion.--

REMARKS

This is a continuation of co-pending application number 09/101,630, filed July 14, 1998, which is the U.S. national phase filing of PCT/US96/13062 filed on August 7, 1996.

This application is being filed for the purposes of provoking an interference with Fleming et al., U.S. Patent No. 5,694,503, which issued on December 2, 1997.

Applicant is preparing the information called for by 37 CFR §1.607(a) and will submit that information when completed.

No additional claim fees beyond those submitted herewith are believed to be necessary for the entry of this preliminary amendment. However, if such fees are required, the Commissioner is hereby authorized to charge the fees to Deposit Account No. 11-1158.

Respectfully submitted,

Date: 12/1/98

Maurice Klee
Maurice M. Klee, Ph.D.
Reg. No. 30,399
Attorney for Applicant
1951 Burr Street
Fairfield, CT 06430
(203) 255-1400

RECEIVED

ATHERMAL OPTICAL DEVICE

FIELD OF THE INVENTION

This invention relates to a temperature compensated, athermal optical device and, in particular, to an optical fiber reflective grating device incorporating a negative expansion beta-eucryptite substrate to produce an athermal optical fiber reflective grating device, and to a method of producing the athermal optical fiber reflective grating device.

BACKGROUND OF THE INVENTION

Index of refraction changes induced by UV light are useful in producing complex, narrow-band optical components such as filters and channel add/drop devices. These devices can be an important part of multiple-wavelength telecommunication systems. The prototypical photosensitive device is a reflective grating (or Bragg grating), which reflects light over a narrow wavelength band. Typically, these devices have channel spacings measured in nanometers.

There are already known various constructions of optical filters, among them such which utilize the Bragg effect for wavelength selective filtering. US Patent 4,725,110 discloses one method for constructing a filter which involves imprinting at least one periodic grating in the core of the optical fiber by exposing the core through the cladding to the interference pattern of two ultraviolet beams that are directed against the optical fiber at two angles relative to the fiber axis that complement each other to 180°. This results in a reflective grating which is oriented normal to the fiber axis. The frequency of the light reflected by such an optical fiber with the incorporated grating filter is related to the spacing of the grating which varies either with the strain to

which the grating region is subjected, or with the temperature of the grating region, in a clearly defined relationship, which is substantially linear to either one of these parameters.

For a uniform grating with spacing L , in a fiber with an effective index of refraction n and expansion α , the variation of center reflective wavelength, λ_r is given by

$$d\lambda_r/dT = 2L[dn/dT + \alpha n]$$

In silica and germania-silica fiber reflective gratings the variation in center wavelength is dominated by the first term in the brackets, the change of index of refraction with temperature. The expansion term contributes less than ten percent of the total variability. $d\lambda_r/dT$ is typically $0.01 \text{ nm}/^\circ\text{C}$ for a grating with a peak reflectance at 1550 nm .

One practical difficulty in the use of these gratings is their variation with temperature. In as much as the frequency of the light reflected by the fiber grating varies with the temperature of the grating region this basic filter cannot be used in applications where the reflected light frequency is to be independent of temperature. Methods of athermalizing the fiber reflective grating would increase the applications for such gratings.

One method of athermalizing a fiber reflective grating is to thermally control the environment of the grating with an actively controlled thermal stabilization system. Such thermal stabilization is costly to implement and power, and its complexity leads to reliability concerns.

A second athermalization approach is to create a negative expansion which compensates the dn/dT . Devices which employ materials with dissimilar positive thermal expansions to achieve the required negative expansion are known.

US Patent 5,042,898 discloses a temperature compensated, embedded grating, optical waveguide light filtering device having an optical fiber grating. Each end of the fiber is attached to a different one of two compensating members made of materials with such coefficients of thermal expansion relative to one another and to that of the fiber material as to apply to the fiber longitudinal strains, the magnitude of which varies with temperature in such a manner that the changes in the longitudinal strains

substantially compensate for these attributable to the changes in the temperature of the grating

Yoffe, G. W. *et al* in "Temperature-Compensated Optical-Fiber Bragg Gratings" OFC'95 Technical Digest, paper WI4, discloses a device with a mechanical arrangement of metals with dissimilar thermal expansions which causes the distance between the mounting points of an optical fiber to decrease as the temperature rises and reduce the strain in a grating.

Such devices have several undesirable properties. First, fabricating a reliable union with the fiber is difficult in such devices. Second, the mechanical assembly and adjustment of such devices make them costly to fabricate. These systems also show hysteresis, which makes the performance degrade under repeated thermal cycling. Finally some of the approaches require that the grating, which can be several centimeters long, be suspended, making them incompatible with other requirements of passive devices such as insensitivity to mechanical shock and vibration.

Another method of incorporating negative expansion which may be envisaged is to provide a substrate for mounting the optical fiber grating thereon which is fabricated from material with an intrinsic negative coefficient of expansion.

US Patent 4,209,229 discloses lithium-alumina-silica type ceramic glasses, particularly those having stoichiometries, on a mole ratio basis, in the range of 1 Li₂O: 0.5-1.5 Al₂O₃: 3.0-4.5 SiO₂, which are particularly adapted for use as protective outer layers over fused silicas and other cladding materials for optical fiber waveguide members. When these lithium aluminosilicate glasses are cerammed, that is, heat treated to produce nucleated crystallizations, the dominant crystal phase developed is either beta-eucryptite or beta-quartz solid solution. Nucleating agents such as TiO₂ and ZrO₂ are used to initiate crystallization of the glass. The glasses produced in this manner have negative coefficients of expansion averaging about $-1.4 \times 10^{-7}/^{\circ}\text{C}$ over the range of 0°-600°C. Thin layers of these lithium aluminosilicate glasses can be cerammed to develop fine-grained crystal phases by heat treating a coated filament at 700-1400°C for a time not exceeding one minute. The cooled outer layer exerts a compressive stress on the coated fiber.

US Patent 5,426,714 disclose optical fiber couplers which utilize

beta-eucryptite lithium aluminosilicates having a low or negative coefficient of thermal expansion as fillers for polymeric resins. The glass-ceramics were obtained by melting the composition in a platinum crucible at 1650°C. The glass was then drigaged, cerammed and ground to a powder. A beta-eucryptite composition of 15.56 wt. % Li₂O, 53.125 wt. % Al₂O₃, 31.305 wt. % SiO₂ having a negative coefficient of thermal expansion of $-86 \times 10^{-7} / ^\circ\text{C}$ measured between -40°C and +80°C is disclosed (Col. 4, lines 24-28).

It is an object of this invention to provide a temperature compensated optical device which is an athermal device.

It is an object of this invention to provide a temperature compensated optical fiber reflective grating device which is an athermal device.

It is an object of this invention to provide a temperature compensated optical fiber reflective grating device which tolerates shock and vibration.

It is an object of this invention to provide a temperature compensated optical fiber reflective grating device which has a stable center wavelength.

It is an object of this invention to provide a temperature compensated optical fiber reflective grating device in which the grating region of the fiber is straight.

SUMMARY OF THE INVENTION

Briefly stated the invention provides a method for producing an athermal optical device comprising; providing a negative expansion substrate having an upper surface; mounting a thermally sensitive, positive expansion optical component onto the substrate upper surface and affixing the component to the substrate at at least two spaced apart locations.

In another aspect of the invention there is provided an athermal optical device comprising; a negative expansion substrate having an upper surface; a thermally sensitive, positive expansion optical component affixed to the substrate upper surface at at least two spaced apart locations.

In another aspect of the invention there is provided a method for producing an athermal optical fiber grating device comprising; providing a negative expansion substrate having an upper surface and first and second ends; mounting an optical fiber

with at least one grating defined therein onto the substrate upper surface such that the grating lies between and at a distance from each end; and affixing the optical fiber to the substrate at at least two spaced apart locations.

In another aspect of the invention there is provided an athermal optical fiber grating device comprising; a negative expansion substrate having an upper surface and first and second ends; an optical fiber affixed to the substrate upper surface at at least two spaced apart locations; and a grating defined in the optical fiber between and at a distance from each end.

The novel aspects of this invention are set forth with particularity in the appended claims. The invention itself, together with further objects and advantages thereof may be more fully comprehended by reference to the following detailed description of a presently preferred embodiment of the invention taken in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a schematic drawing of an embodiment of an athermal optical fiber grating device.

Figure 2 is a schematic drawing of a second embodiment of an athermal optical fiber grating device.

Figure 3 is a schematic drawing of a third embodiment of an athermal optical fiber grating device.

Figure 4 is an enlarged view of the affixing channel depicted in Figure 3.

Figure 5 is a schematic drawing of a fourth embodiment of an athermal optical fiber grating device.

Figure 6 is a thermal expansion graph of a beta-eucryptite glass-ceramic.

Figure 7 is a thermal expansion graph of a beta-eucryptite glass-ceramic.

Figure 8 is a graph of an athermalized grating center wavelength .

Figure 9 is a schematic drawing of an embodiment of an athermal optical fiber fused coupler device.

Figure 10 is a schematic drawing of an embodiment of an athermal planar waveguide device.

DETAILED DESCRIPTION OF THE INVENTION

Thermally sensitive optical devices of the invention include optical waveguides, UV photo induced fiber gratings and optical fiber couplers. The optical fiber reflective gratings used in the device of this invention are well known to those familiar with the art, for example, UV photo induced gratings of the Bragg type.

In this invention, the athermalization approach taken is to create a negative expansion which compensates for the positive change in refractive index of the optical fiber with a change in temperature. The coefficient of expansion required is on the order of $-50 \times 10^{-7}/^{\circ}\text{C}$, or perhaps slightly higher because of stress-optic effects. In this approach, the fiber containing the grating is mounted, preferably under tension, on a substrate that imparts a negative thermal expansion to the fiber. Thus, as the temperature is increased, the tension is reduced, but the fiber is never put into compression (as this would be mechanically unstable).

The optical fiber, for example a germania-silica fiber, is affixed to a substrate with an intrinsic negative coefficient of expansion. The increase of the index of refraction of the fiber caused mostly by the thermal drift, is compensated by a negative mechanical expansion. The negative expansion is imparted by a substrate fabricated from a material based on a silica based glass-ceramic possessing an intrinsic negative coefficient of expansion. The negative expansion is obtained by inducing micro crystals in the glass-ceramic which undergo a reconstructive phase change on heating at high temperatures, for example about 1300°C , to produce a highly ordered beta-eucryptite (*i.e.* stuffed beta-quartz) structure.

A suitable material for the substrate, beta-eucryptite, has been identified which provides compensation over a wide temperature range, for example -40° to $+85^{\circ}\text{C}$, which is mechanically robust against creep and shows minimal thermal hysteresis. In some applications an even wider range of temperatures may be tolerated. The beta-eucryptite material is based on a highly ordered lithium aluminosilicate glass-ceramic which is, in itself, a stuffed derivative of beta-quartz containing aluminum and lithium. Significant titania, for example >2 wt%, is also required to be present as a nucleating agent to induce crystallization of the solid solution in order to minimize grain size and reduce hysteresis due to inter granular micro cracking.

The beta-eucryptite solid solution of preference lies between stoichiometric LiAlSiO_4 ($\text{Li}_2\text{O}:\text{Al}_2\text{O}_3:2\text{SiO}_2 = 1:1:2$) and $\text{Li}_2\text{Al}_2\text{Si}_3\text{O}_{10}$ ($\text{Li}_2\text{O}:\text{Al}_2\text{O}_3:3\text{SiO}_2 = 1:1:3$), and the nucleating agents TiO_2 and, optionally, ZrO_2 , are added in such a way as to produce accessory phases Al_2TiO_5 or ZrTiO_4 , preferably the former, for the lowest thermal expansion coefficients.

This glass-ceramic has a true negative expansion micro crystalline phase, strongly along one axis, c-axis, mildly positive along the other, a-axis and is mechanically stable over a wide temperature range, showing little hysteresis or physical property degradation.

In weight percent, a suitable glass-ceramic composition range is as follows: SiO_2 43-55%, Al_2O_3 31-42%, Li_2O 8-11%, TiO_2 2-6%, and ZrO_2 0-4%.

The beta-eucryptite substrate of the invention is preferably a material with a coefficient of thermal expansion between $-30 \times 10^{-7}/^\circ\text{C}$ and $-90 \times 10^{-7}/^\circ\text{C}$, more preferably $-50 \times 10^{-7}/^\circ\text{C}$ to $-75 \times 10^{-7}/^\circ\text{C}$, even more preferably $-55 \times 10^{-7}/^\circ\text{C}$.

In order to produce material with this degree of negative expansion the beta-eucryptite has to be very highly ordered to form alternating AlO_4 and SiO_4 tetrahedra. This is achieved by heating the crystallized phase at a top temperature near 1300°C for at least 3 hours, preferably about 4 hours. In order to prevent cracking of the glass a thermal schedule is used which requires heating the glass through a range of temperatures which maintains a desired viscosity during crystallization near 5×10^{10} poises thereby precluding sagging or cracking.

The beta-eucryptite materials of the prior art were not obtained in a slab form but rather were prepared as thin coatings or crushed powders. In order to produce a glass-ceramic substrate of the desired size (potentially several centimeters long) a glass of some stability is required. The molten glass must be cast into thin slabs, for example < 0.5 in. thick, onto a metal table or mold to ensure rapid cooling. The glass is then annealed at about 700°C - 800°C for several hours and then cooled slowly to avoid undesirable stresses.

EXAMPLES OF BETA-EUCRYPTITE COMPOSITIONS

Example 1

A composition containing on a weight percent basis 50.3% SiO_2 , 36.7% Al_2O_3 ,

9.7% Li_2O and 3.3% TiO_2 is melted at 1600°C in a crucible then the glass is cast onto a cold steel plate to form a disc of about 0.25 to 0.5 in thick. The slab is then cut into bars and heated to 715°C at 300°C/hr , to 765°C at 140°C/hr , to 1300°C at 300°C/hr , held at this temperature for 4 hours then cooled at the furnace cooling rate for several hours to less than about 100°C .

Figure 6 shows a thermal expansion measurement on a 2 inch (50 mm) sample of the material composition of Example 1 which gives an average negative coefficient of expansion of $-78 \times 10^{-7}/^\circ\text{C}$ (measured between 25° - 150°C) and a moderate level of hysteresis as evidenced by the very similar heating and cooling curves.

Example 2

A composition containing on a weight percent basis 49.0% SiO_2 , 37.1% Al_2O_3 , 9.6% Li_2O and 4.3% TiO_2 is melted at 1600°C in a crucible then the glass is cast onto a cold steel plate to form a disc of about 0.25 to 0.5 in (6.3 mm to 12.7 mm) thick. The slab is then cut into bars and heated to 715°C at 300°C/hr , to 765°C at 140°C/hr , to 1300°C at 300°C/hr and held at this temperature for 4 hours, then cooled at the furnace cooling rate for several hours to less than about 100°C . The cooled bar is subjected to four cycles of reheating to 800°C and cooling to ambient temperatures to minimize hysteresis.

Example 3

A composition identical to that of Example 2 was treated to the same conditions except that it is held at 1300°C for only 0.5 hours before cooling, and it was not subjected to further heating cycles.

Figure 7 shows a thermal expansion measurement on the material composition of Examples 2 and 3. Example 2 shows an average negative coefficient of expansion of $-52.8 \times 10^{-7}/^\circ\text{C}$ (measured between 25° - 150°C) and essentially no hysteresis as evidenced by the very similar heating and cooling curves. Example 3 shows zero expansion over the same temperature range without hysteresis.

In order to obtain the desired degree of negative expansion it is preferable that the composition be maintained at the top temperature of 1300°C for about 3 to 4 hours to obtain a highly ordered crystal phase. It is evident that the material of Example 3 which was only maintained at 1300°C for 0.5 hour has a zero coefficient of expansion

and is still relatively disordered.

The heat recycling steps are not essential for achieving satisfactory hysteresis. However, 1 to 4 heat recycling steps may be beneficial. The heating rate is about 300°C per hour and the bar is maintained at 800°C for about 1 hour each cycle.

5 Referring to Figure 1 there is illustrated a first embodiment of the invention. The optical fiber reflective grating device 20 has a substrate 22 formed from a flat block of a negative expansion material, such as beta-eucryptite. An optical fiber 24 having at least one UV-induced reflective grating 26 written therein is mounted on the surface 28 and attached at either end of the surface at points 30 and 32. It is important that the
10 fiber is always straight and not subject to compression as a result of the negative expansion and thus the fiber is usually mounted under tension. Before attachment the fiber is placed under a controlled tension, as shown schematically by the use of a weight 34. The proper choice of tension assures that the fiber is not under compression at all anticipated use temperatures. However, the fiber can be under tension at all anticipated
15 use temperatures. The required degree of tension to compensate for the negative expansion in a particular application can readily be calculated by those with skill in this art.

The attachment material could be an organic polymer, for example an epoxy cement, an inorganic frit, for example ground glass, ceramic or glass-ceramic material,
20 or a metal. In one embodiment the fiber is tacked to the substrate with a UV-cured epoxy adhesive. Mechanical means for attaching the fiber can also be used.

Generally the optical fiber reflective grating is supplied with a coating material surrounding the fiber. In the preferred packaging approach the coating in the grating region of the fiber is left intact while it is removed in the substrate attachment region at
25 each end of the grating. However, the device can have the coating completely removed between the attachment locations. Removal of the coating can be accomplished by one of two methods : a non-contact, non-chemical stripping mechanism or by conventional chemical stripping.

In another embodiment, Figure 2, the fiber is not attached directly to the
30 substrate. Bonding pads 40, 42 made from a material differing from the substrate, for example a glass or a ceramic, are attached to the substrate at either end. The fiber 26 is

mounted to the pads at points 44, 46. These pads afford better attachment properties of the pad to the fiber than could be achieved from the substrate directly to the fiber because of the large thermal expansion mismatch. Suitable pad materials have a coefficient of thermal expansion intermediate between that of the fiber and the substrate for example between -50 and $+5 \times 10^{-7}$, preferably about -20×10^{-7} . Alternatively the pad could be a fused silica with a coefficient of expansion closely matching that of the fiber. The pad allows the stress of this joint induced by both the thermal mismatch and the tension of the fiber, to be spread out over a wider area, lessening the chances of cracking and detachment. The attachment materials for the fiber and pad connections are similar to those used for mounting the fiber directly to the substrate, for example, an epoxy cement, an inorganic frit, for example ground glass, ceramic or glass-ceramic material, or a metal.

In another embodiment, Figure 3, the negative expansion of the substrate material 22 is used to create a clamping force on the fiber. The attachment feature, which might be a hole or channel 50, 52 in a raised portion 54, 56 of the substrate, is formed in the substrate at room temperature with a gap that is very slightly smaller than the fiber. Referring to Figure 4, by lowering the temperature to a point lower than any anticipated use temperature, the substrate expands and allows the insertion of the fiber 24 into the channel 50. Warming of the substrate then causes substrate contraction and creates a clamping force for holding the fiber in the channel.

In another embodiment, Figure 5, the fiber 24 is attached to the substrate at points 30, 32 and the intermediate fiber length 60 is cushioned by a low modulus damping material 62. This low-modulus material, for example a silicone rubber coating surrounding the fiber or a pad of a silicone rubber, a natural or synthetic rubber or mixtures thereof, between the fiber and the substrate protects the fiber reflective grating against external perturbations such as mechanical shock or vibration. Bowing of the fiber is also minimized. In one embodiment the low modulus material is adhesively attached to the fiber and the substrate.

Mounting the fiber under tension will alter the optical properties of the device (for example, the center wavelength of a grating). This can be addressed by biasing the device with a reflective grating written therein to account for the tension, or it can be

done by mounting a fiber, for example a germania doped silica fiber, without a reflective grating written therein under tension and then exposing the fiber to UV light in order to fabricate the grating in the device *in situ*.

In a typical embodiment of the invention the temperature sensitivity of the center wavelength is about 0.0125 nm/°C, the stress sensitivity of the center wavelength is 0.125 nm shift for 9g of tension, the bare fiber has a diameter of 125 microns, a coated fiber has a diameter of 250 microns. The strength of the fiber is >200 kpsi and therefore has a very high reliability.

Example Of An Athermalized Grating On A Beta-Eucryptite Substrate

The grating was written in a photorefractive-sensitive fiber, Corning SMF-228 fiber, and the fiber was hydrogen loaded at 100 atmospheres in a hydrogen chamber for one week. After removal of the fiber from the hydrogen chamber, a length of approximately 30 mm of coating was removed by mechanical stripping and the fiber was exposed to 240 nm laser irradiation to create the grating. The fiber was then mounted to a substrate of beta-eucryptite, prepared essentially according to the method of Example 2, under a 10 kpsi tension using a UV-curable epoxy adhesive. The assembled grating was heated to 125°C for 2 hours to out diffuse any remaining hydrogen and to eliminate low stability UV-induced traps. The fiber was thermally cycled between -40°C and +125°C. A reference fiber was treated in exactly the same way, except it was not attached to a substrate. The grating center wavelength (Figure 8) varies by approximately 1.9 nm from -40°C to +125°C when not attached to the substrate and by only 0.2 nm when attached to the substrate.

Although this invention has been described for UV photo induced gratings it can also be applied to the packaging of other thermally sensitive devices. For instance, optical fiber couplers and optical waveguides could be athermalized by attachment to a negative expansion substrate.

An optical fiber fused coupler has two or more fibers fused together at one or more points along their length and is mounted on a substrate. Such couplers are thermally sensitive which results in a certain amount of thermal instability. Especially sensitive are biconically tapered couplers in which interferometric effects are used, for example a Mach-Zehnder interferometer. Such couplers can be athermalized by

mounting the coupler to a negative expansion substrate, such as the beta-eucryptite described in Example 2 above. Referring to Figure 9 there is illustrated a fused biconical coupler device 70 which includes a negative expansion substrate 72 to which are mounted two fibers 74, 76. The fibers are fused together at regions 78, 80. The fibers are attached to the substrate near the ends at locations 82, 84 in the same manner as described above for the optical fiber reflective grating.

Waveguides can be defined, for example, in optical fibers or planar substrates. Such waveguides are thermally sensitive which results in a certain amount of thermal instability. Such waveguides can be athermalized by mounting the waveguide to a negative expansion substrate, such as the beta-eucryptite described in Example 2 above. Referring to Figure 10, there is illustrated a planar waveguide device 90 which includes a negative expansion substrate 92 on which is adhesively mounted a layer of material 94 in which a planar waveguide 96 is fabricated by methods well known to those skilled in this art. The waveguide material can be, for example, a doped silica such as a germania silicate, other suitable glass compositions, polymers and semiconductors, including semiconductors with gain, such as laser diodes.

The device of this invention is a completely passive system and mechanically simple, and demonstrates athermalization. The method of producing the device is advantageous because it provides temperature compensated optical devices which tolerate shock and vibration and are thermally stable.

While the invention has been described in connection with a presently preferred embodiment thereof, those skilled in the art will recognize that many modifications and changes may be made therein without departing from the true spirit and scope of the invention, which accordingly is intended to be defined solely by the appended claims.

WHAT IS CLAIMED IS:

1. A method for producing an athermal optical device comprising
providing a negative expansion substrate having an upper surface;
mounting a thermally sensitive, positive expansion optical component onto the
substrate upper surface and
affixing the component to the substrate at at least two spaced apart locations.

2. The method according to Claim 1, wherein the substrate comprise a
beta-eucryptite glass-ceramic.

3. The method according to Claim 2, in which the beta-eucryptite comprises
SiO₂ 43-55%, Al₂O₃ 31-42%, Li₂O 8-11%, TiO₂ 2-6%, and ZrO₄ 0-4% on a weight
percent basis.

4. The method according to Claim 1, wherein the component is affixed by a
layer of attachment material.

5. The method according to Claim 4, wherein the attachment material is one of a
polymer, a frit and a metal.

6. The method according to Claim 1, in which the optical component is an
optical fiber grating.

7. The method according to Claim 1, in which the optical component is an
optical fiber coupler, the coupler comprising at least two optical fibers fused together at
one or more points along their lengths.

8. The method according to Claim 1, in which the optical component is a
waveguide.

9. The method according to Claim 8, in which the waveguide is a planar

waveguide.

10. A method for producing an athermal optical fiber grating device comprising
providing a negative expansion substrate having an upper surface and first and
5 second ends;

mounting an optical fiber with at least one grating defined therein onto the
substrate upper surface such that the grating lies between and at a distance from each
end; and

affixing the optical fiber to the substrate at at least two spaced apart locations.

11. The method according to Claim 10, further comprising applying a sufficient
tension to the optical fiber before the affixing step to maintain the fiber under tension at
all anticipated use temperatures.

12. The method according to Claim 10, wherein the optical fiber is affixed to
the substrate upper surface at a location between the grating and the first end and at a
location between the grating and the second end.

13. The method according to Claim 12, wherein the fiber is affixed by a layer of
attachment material.

14. The method according to Claim 14, wherein the attachment material is one
of a polymer, a frit and a metal.

15. The method according to Claim 14, wherein the polymer is an epoxy
adhesive.

16. The method according to Claim 12, wherein the affixing step comprises;
bonding a pad of material having a coefficient of expansion intermediate between that
of the fiber and the substrate to the upper substrate surface at each affixing location and
affixing the fiber to each pad.

17. The method according to Claim 12, wherein the fiber is cushioned along substantially the entire length of the fiber between the affixing locations by a low-modulus damping material.

5 18. The method according to Claim 12, wherein the substrate has a channel formed at each of the affixing locations of the upper surface sized to receive the fiber at a temperature lower than any anticipated use of the device and to clamp on the fiber at a normal use temperature range, further comprising;

cooling the substrate to the lower temperature;

10 inserting the fiber in each channel; and

warming the substrate to the normal use temperature range to clamp the fiber.

19. The method according to Claim 10, wherein the substrate comprise a beta-eucryptite glass-ceramic.

15 20. The method according to Claim 19, in which the beta-eucryptite comprises SiO_2 43-55%, Al_2O_3 31-42%, Li_2O 8-11%, TiO_2 2-6%, and ZrO_2 0-4% on a weight percent basis.

20 21. A method for producing an athermal optical fiber grating device comprising: providing a negative expansion substrate having an upper surface and first and second ends;

mounting a photorefractive-sensitive optical fiber onto the substrate upper surface;

25 applying a sufficient tension to the optical fiber to maintain the fiber under tension at all anticipated use temperatures;

affixing the optical fiber to the substrate at at least two spaced apart locations;

and

30 exposing the optical fiber to UV light in order to define at least one optical grating therein such that the grating lies between and at a distance from each end either before or after the mounting step.

22. The method according to Claim 21, wherein the substrate comprise a beta-eucryptite glass-ceramic.

23. An athermal optical device comprising:

a negative expansion substrate having an upper surface;

a thermally sensitive, positive expansion optical component affixed to the substrate upper surface at at least two spaced apart locations.

24. The device according to Claim 23, in which the substrate comprises a beta-eucryptite glass-ceramic.

25. The device according to Claim 24, in which the beta-eucryptite comprises SiO₂ 43-55%, Al₂O₃ 31-42%, Li₂O 8-11%, TiO₂ 2-6%, and ZrO₄ 0-4% on a weight percent basis.

26. The device according to Claim 23, in which the optical component is an optical fiber grating.

27 The device according to Claim 23, in which the optical component is an optical fiber coupler, the coupler comprising at least two optical fibers fused together at one or more points along their lengths.

28. The device according to Claim 23, in which the optical component is a waveguide.

29 The device according to Claim 28, in which the waveguide is a planar waveguide.

30. An athermal optical fiber grating device comprising:

a negative expansion substrate having an upper surface and first and second ends;

an optical fiber affixed to the substrate upper surface at at least two spaced apart locations; and

a grating defined in the optical fiber between and at a distance from each substrate end.

5

31. The device according to Claim 30, in which the optical fiber is affixed to the substrate upper surface at first and second spaced apart locations, the first location is between the grating and the first substrate end and the second location is between the grating and the second substrate end.

10

32. The device according to Claim 30, wherein the fiber is affixed by a layer of attachment material.

15

33. The device according to Claim 32, in which the attachment material is one of a polymer, a frit and a metal.

34. The device according to Claim 33, in which the polymer is an epoxy adhesive.

20

35. The device according to Claim 31, further comprising a bonding pad having a coefficient of expansion intermediate between that of the fiber and the substrate mounted between the optical fiber and the substrate at each of the first and second locations, the optical fiber being bonded to each bonding pad and each bonding pad being affixed to the substrate.

25

36. The device according to Claim 31, further comprising a low modulus damping material connected to substantially the entire length of the fiber between the affixing locations.

30

37. The device according to Claim 31, in which each affixing location comprises a channel sized to receive the fiber at a temperature lower than any anticipated use of

the device and to clamp on the fiber at normal use temperatures

38. The device according to Claim 30, in which the substrate comprises a beta-eucryptite glass-ceramic.

5

39. The device according to Claim 38, in which the beta-eucryptite comprises SiO₂ 43-55%, Al₂O₃ 31-42%, Li₂O 8-11%, TiO₂ 2-6%, and ZrO₄ 0-4% on a weight percent basis.

10

40. The device according to Claim 39, in which the beta-eucryptite has a negative coefficient of thermal expansion between $-30 \times 10^{-7}/^{\circ}\text{C}$ and $-90 \times 10^{-7}/^{\circ}\text{C}$.

B67C 23/00 (20060101)

ABSTRACT OF THE DISCLOSURE

An athermal optical device and a method for producing the device, such as an athermal optical fiber reflective grating, are described. The athermal optical fiber reflective grating device comprises a negative expansion substrate, an optical fiber mounted on the substrate surface, and a grating defined in the optical fiber. The method for producing the athermal optical fiber reflective grating device comprises providing a negative expansion substrate, mounting an optical fiber with at least one reflective grating defined therein onto the substrate upper surface, and affixing the optical fiber to the substrate at at least two spaced apart locations.

B6T02T" 43T0260

1 / 5

FIG. 1

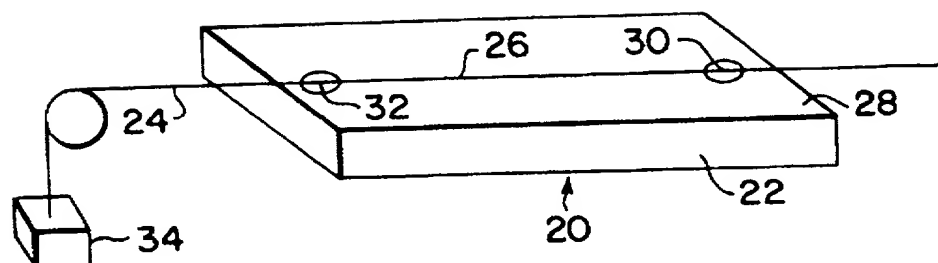


FIG. 2

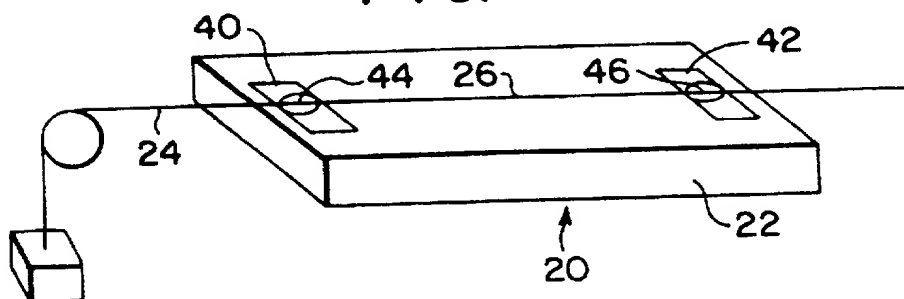
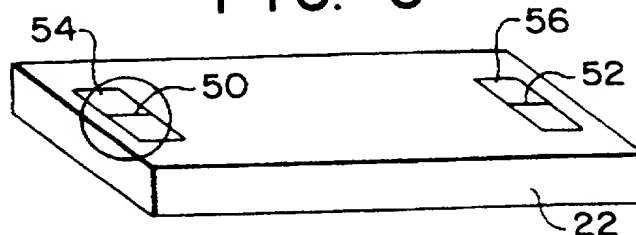


FIG. 3



SUBSTITUTE SHEET (RULE 26)

FIG. 4

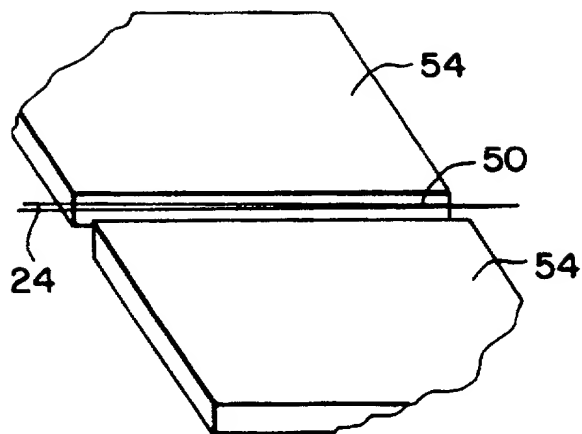


FIG. 5

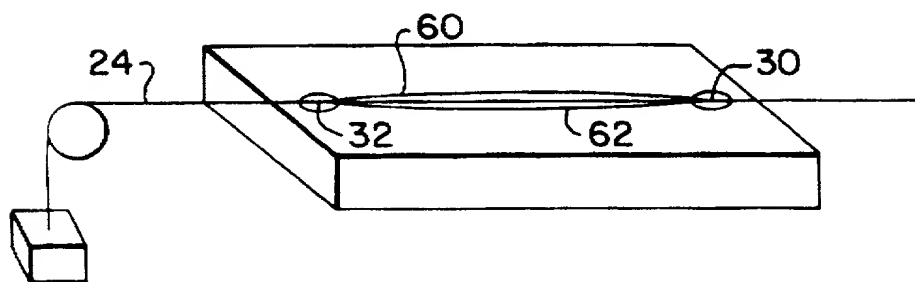


FIG. 6

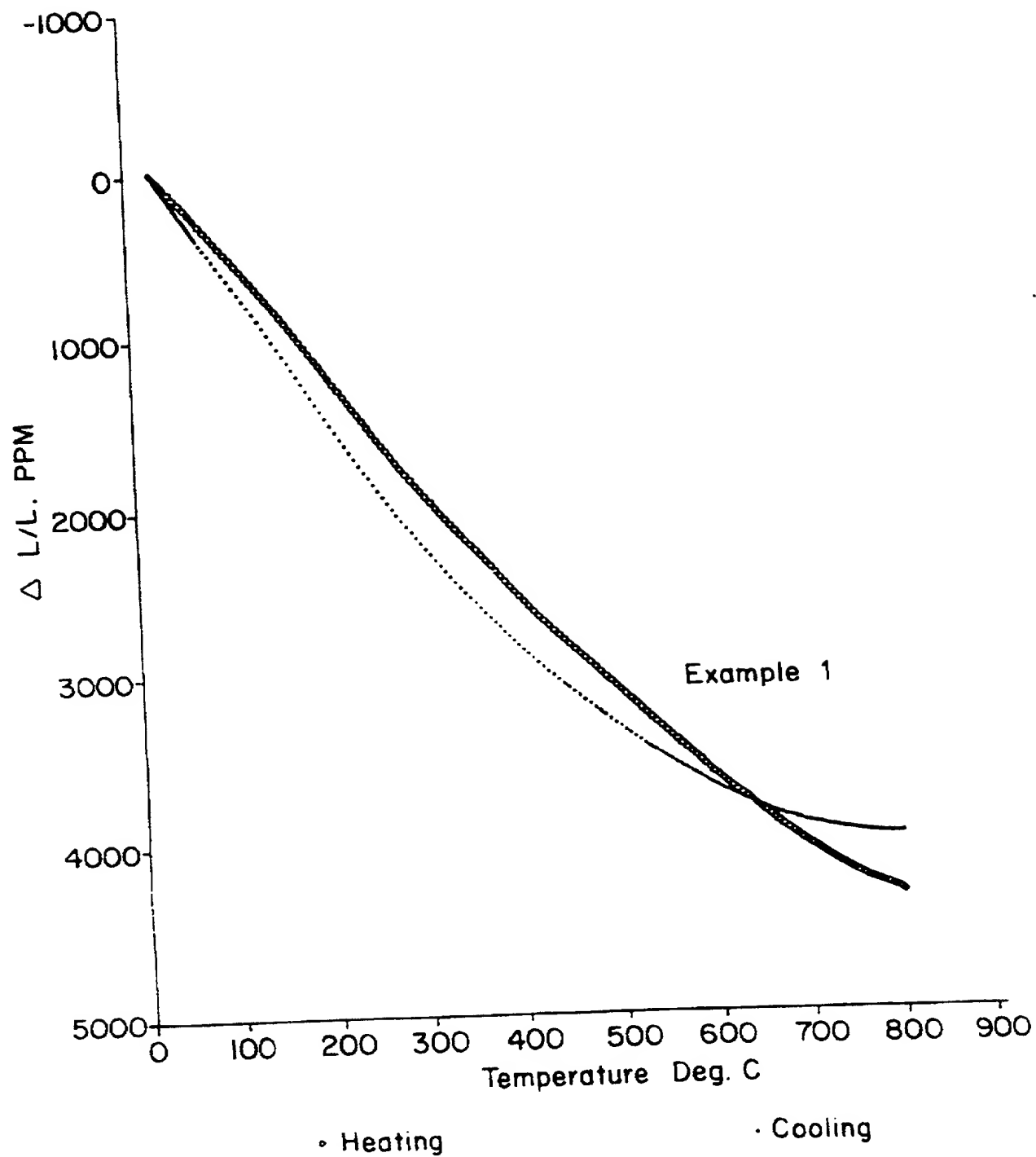
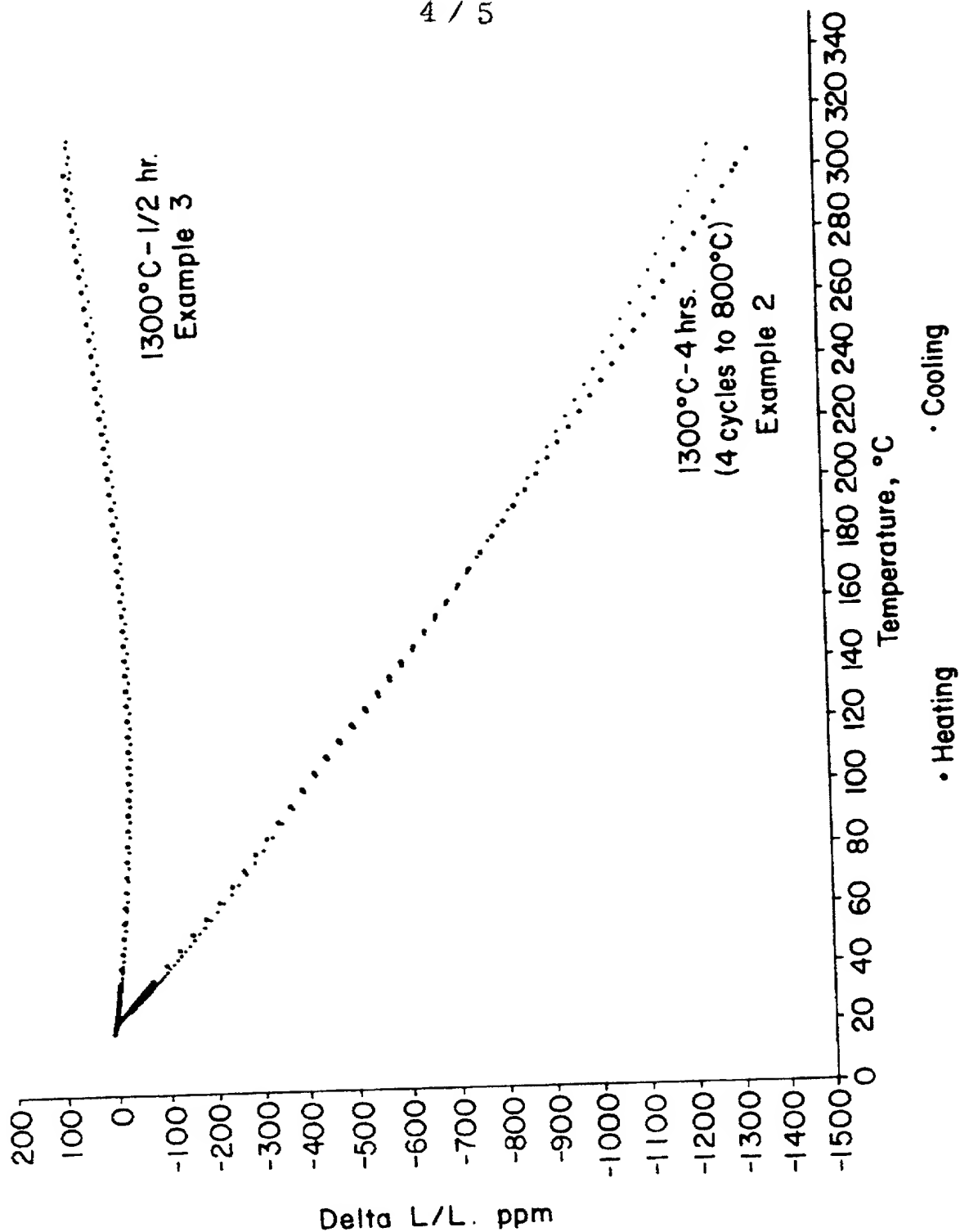


FIG. 7



5 / 5

FIG. 8

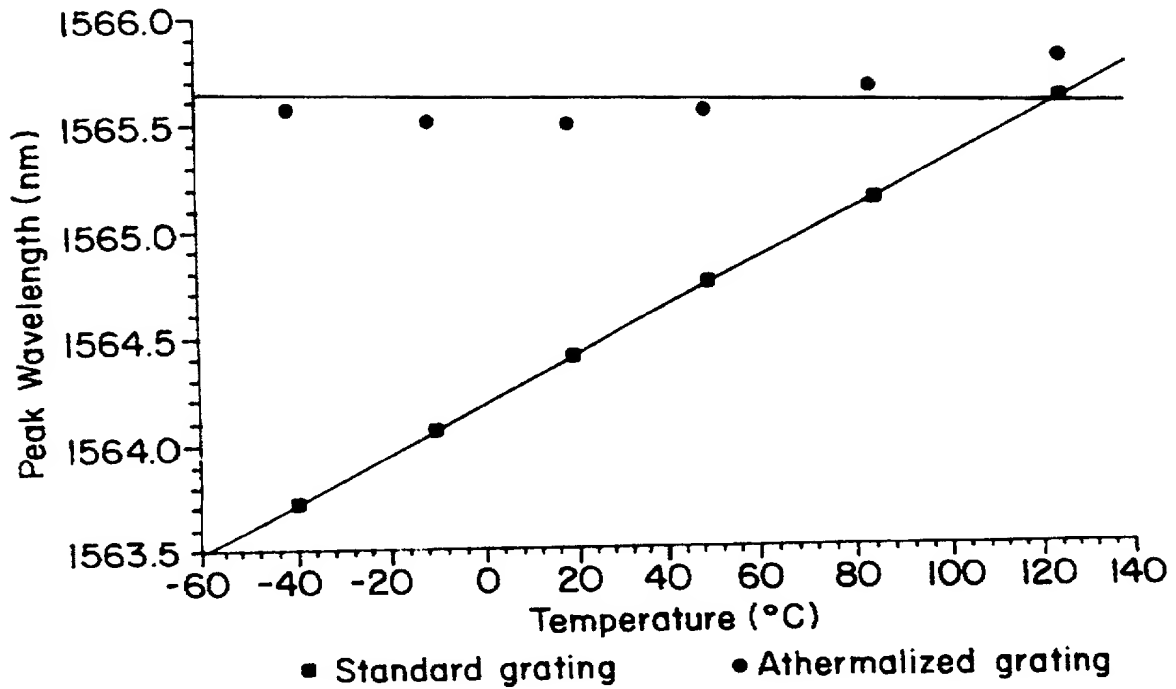


FIG. 9

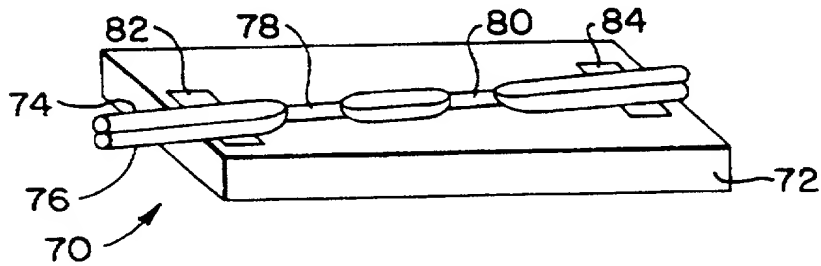
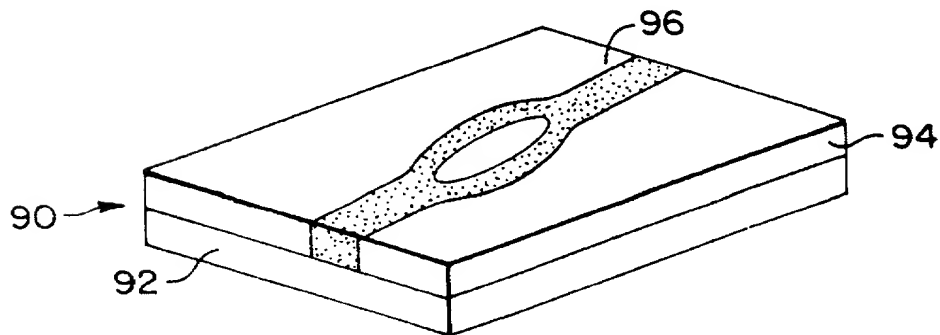


FIG. 10



Please type a plus sign (+) inside this box → ☐

PTO/SB/01 (12-97)

Approved for use through 9/30/00. OMB 0651-0032

Patent and Trademark Office; U.S. DEPARTMENT OF COMMERCE

Under the Paperwork Reduction Act of 1995, no persons are required to respond to a collection of information unless it contains a valid OMB control number.

**DECLARATION FOR UTILITY OR
DESIGN
PATENT APPLICATION
(37 CFR 1.63)**

☒ Declaration Submitted with Initial Filing OR ☐ Declaration Submitted after Initial Filing (surcharge (37 CFR 1.16 (e)) required)

Attorney Docket Number CGW-235

First Named Inventor Beall

COMPLETE IF KNOWN

Application Number

/

Filing Date

Group Art Unit

Examiner Name

As a below named inventor, I hereby declare that:

My residence, post office address, and citizenship are as stated below next to my name.

I believe I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled:

Athermal Optical Device

the specification of which

(Title of the Invention)

☐ is attached hereto
OR

☒ was filed on (MM/DD/YYYY) 08/07/1996

as United States Application Number or PCT International

Application Number PCT/US96/13062 and was amended on (MM/DD/YYYY) (if applicable).

I hereby state that I have reviewed and understand the contents of the above identified specification, including the claims, as amended by any amendment specifically referred to above.

I acknowledge the duty to disclose information which is material to patentability as defined in 37 CFR 1.56.

I hereby claim foreign priority benefits under 35 U.S.C. 119(a)-(d) or 365(b) of any foreign application(s) for patent or inventor's certificate, or 365(a) of any PCT international application which designated at least one country other than the United States of America, listed below and have also identified below, by checking the box, any foreign application for patent or inventor's certificate, or of any PCT international application having a filing date before that of the application on which priority is claimed.

Prior Foreign Application Number(s)	Country	Foreign Filing Date (MM/DD/YYYY)	Priority Not Claimed	Certified Copy Attached?	
				YES	NO
			<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
			<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
			<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
			<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

☐ Additional foreign application numbers are listed on a supplemental priority data sheet PTO/SB/02B attached hereto:

I hereby claim the benefit under 35 U.S.C. 119(e) of any United States provisional application(s) listed below.

Application Number(s)	Filing Date (MM/DD/YYYY)	<input type="checkbox"/> Additional provisional application numbers are listed on a supplemental priority data sheet PTO/SB/02B attached hereto.
60/010,058	01/16/1996	

(Page 1 of 2)

Burden Hour Statement: This form is estimated to take 0.4 hours to complete. Time will vary depending upon the needs of the individual case. Any comments on the amount of time you are required to complete this form should be sent to the Chief Information Officer, Patent and Trademark Office, Washington, DC 20231. DO NOT SEND FEES OR COMPLETED FORMS TO THIS ADDRESS. SEND TO: Assistant Commissioner for Patents, Washington, DC 20231

Please type a plus sign (+) inside this box → ☐

PTO/SB/01 (12-97)
Approved for use through 9/30/00. OMB 0651-0032
Patent and Trademark Office; U.S. DEPARTMENT OF COMMERCE
Under the Paperwork Reduction Act of 1995, no persons are required to respond to a collection of information unless it contains a valid OMB control number.

DECLARATION — Utility or Design Patent Application

I hereby claim the benefit under 35 U.S.C. 120 of any United States application(s), or 365(c) of any PCT international application designating the United States of America, listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States or PCT International application in the manner provided by the first paragraph of 35 U.S.C. 112, I acknowledge the duty to disclose information which is material to patentability as defined in 37 CFR 1.56 which became available between the filing date of the prior application and the national or PCT international filing date of this application.

U.S. Parent Application or PCT Parent Number	Parent Filing Date (MM/DD/YYYY)	Parent Patent Number (if applicable)

☐ Additional U.S. or PCT international application numbers are listed on a supplemental priority data sheet PTO/SB/02B attached hereto.

As a named inventor, I hereby appoint the following registered practitioner(s) to prosecute this application and to transact all business in the Patent and Trademark Office connected therewith:

☐ Customer Number OR
☒ Registered practitioner(s) name/registration number listed below

Place Customer
Number Bar Code
Label here

Name	Registration Number	Name	Registration Number
Maurice M. Klee	30,399		
Alfred L. Michaelson	24,511		
Edward F. Murphy	38,251		

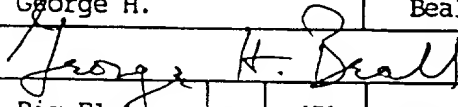
☐ Additional registered practitioner(s) named on supplemental Registered Practitioner Information sheet PTO/SB/02C attached hereto.

Direct all correspondence to: ☐ Customer Number or Bar Code Label OR ☒ Correspondence address below

Name	Maurice M. Klee					
Address	Attorney at Law					
Address	1951 Burr Street					
City	Fairfield	State	CT	ZIP	06430	
Country	US	Telephone	203 255-1400	Fax	203 254-1101	

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under 18 U.S.C. 1001 and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

Name of Sole or First Inventor: ☐ A petition has been filed for this unsigned inventor

Given Name (first and middle if any)				Family Name or Surname			
George H.				Beall			
Inventor's Signature						Date	7/8/98
Residence: City	Big Flats	State	NY	Country	US	Citizenship	CA
Post Office Address							
Post Office Address	16 Woodland Drive						
City	Big Flats	State	NY	ZIP	14814	Country	US

☒ Additional inventors are being named on the 1 supplemental Additional Inventor(s) sheet(s) PTO/SB/02A attached hereto

Please type a plus sign (+) inside this box → ☐

PTO/SB/02A (3-97)
Approved for use through 9/30/98. OMB 0651-0032
Patent and Trademark Office, U.S. DEPARTMENT OF COMMERCE
Under the Paperwork Reduction Act of 1995, no persons are required to respond to a collection of information unless it contains a valid OMB control number.

DECLARATION

ADDITIONAL INVENTOR(S)
Supplemental Sheet
Page 1 of 1

Name of Additional Joint Inventor, if any:				<input type="checkbox"/> A petition has been filed for this unsigned inventor			
Given Name (first and middle [if any])				Family Name or Surname			
David L.				Weidman			
Inventor's Signature	<i>David L. Weidman</i>			Date	7/10/98		
Residence: City	Corning	State	NY	Country	US	Citizenship	US
Post Office Address							
Post Office Address	17 Upper Drive						
City	Corning	State	NY	ZIP	14830	Country	US
Name of Additional Joint Inventor, if any:				<input type="checkbox"/> A petition has been filed for this unsigned inventor			
Given Name (first and middle [if any])				Family Name or Surname			
Inventor's Signature				Date			
Residence: City		State		Country		Citizenship	
Post Office Address							
Post Office Address							
City		State		ZIP		Country	
Name of Additional Joint Inventor, if any:				<input type="checkbox"/> A petition has been filed for this unsigned inventor			
Given Name (first and middle [if any])				Family Name or Surname			
Inventor's Signature				Date			
Residence: City		State		Country		Citizenship	
Post Office Address							
Post Office Address							
City		State		ZIP		Country	

Burden Hour Statement: This form is estimated to take 0.4 hours to complete. Time will vary depending upon the needs of the individual case. Any comments on the amount of time you are required to complete this form should be sent to the Chief Information Officer, Patent and Trademark Office, Washington, DC 20231. DO NOT SEND FEES OR COMPLETED FORMS TO THIS ADDRESS. SEND TO: Assistant Commissioner for Patents, Washington, DC 20231.